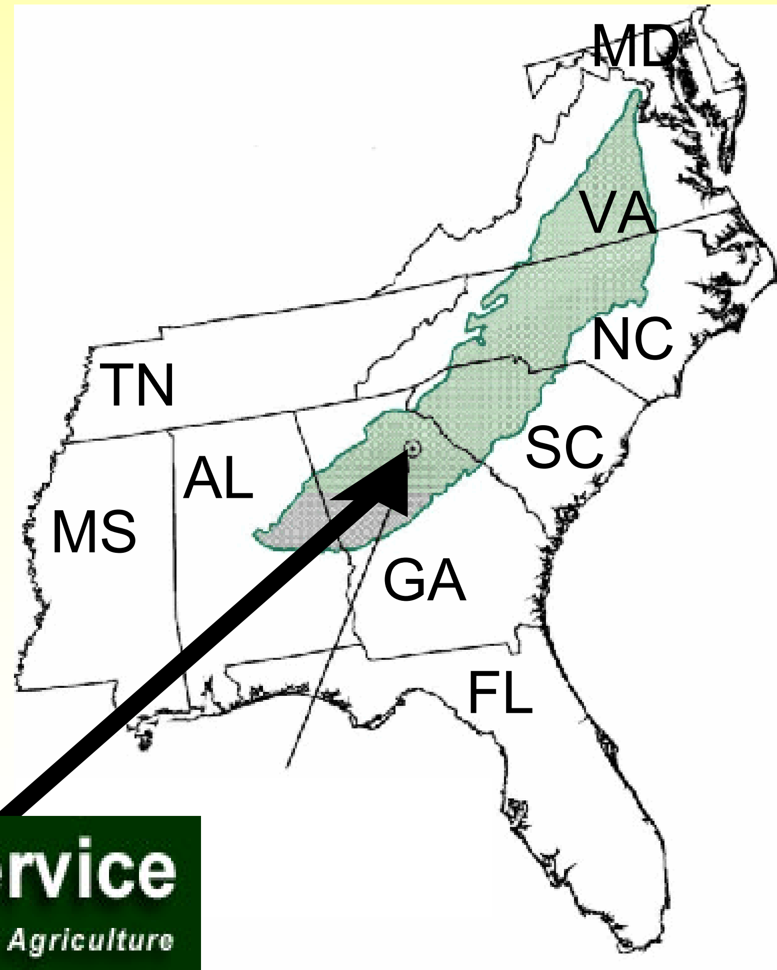
Conservation Agricultural Management to Sequester Soil Organic Carbon

Alan J. Franzluebbers
Ecologist

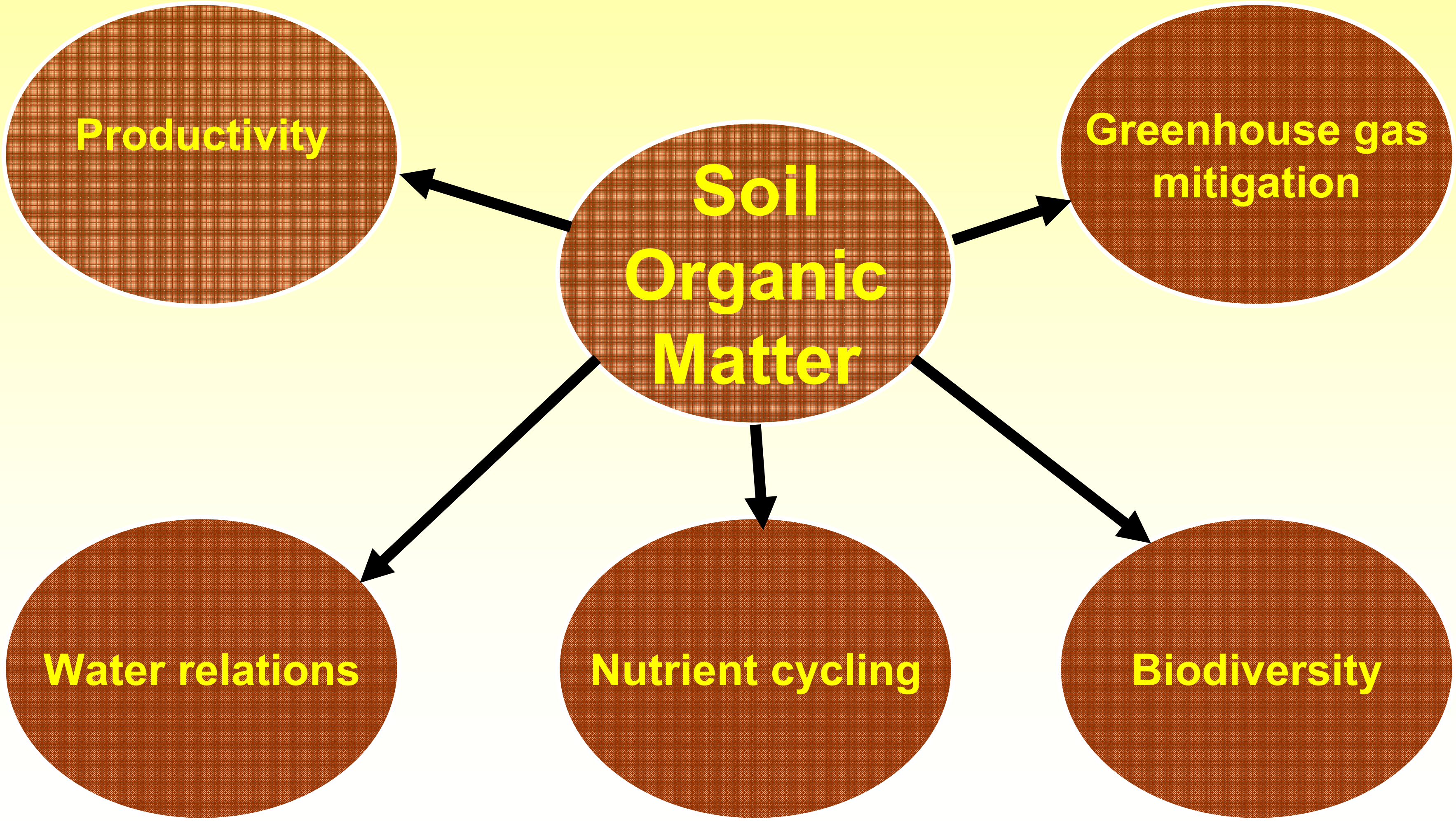
Watkinsville GA



Agricultural Research Service
the in-house research arm of the U.S. Department of Agriculture

Soil Organic Matter

Ecosystem services



Management Approaches

Focus on maximizing carbon input

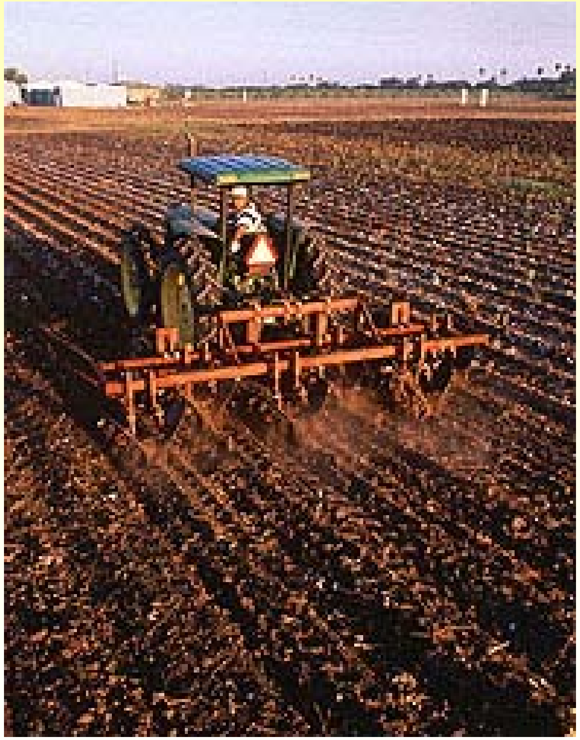
ARS Image Number K5141-4

- ✓ **Plant selection**
  - Species, cultivar, variety
  - Growth habit (perennial / annual)
  - Rotation sequence
  - Biomass energy crops
- ✓ **Tillage**
  - Type
  - Frequency
- ✓ **Fertilization**
  - Rate, timing, placement
  - Organic amendments
- ✓ **Integrated management**
  - Pest control
  - Crop / livestock systems

Management Approaches

Focus on minimizing carbon loss from soil

- ✓ **Reducing soil disturbance**
  - Less intensive tillage
  - Controlling erosion
- ✓ **Utilizing available soil water**
  - Promotes optimum plant growth
  - Reduces soil microbial activity
- ✓ **Maintaining surface residue cover**
  - Increased plant water use and production
  - More fungal dominance in soil



ARS Image Number K7520-2

Soil Carbon Sequestration

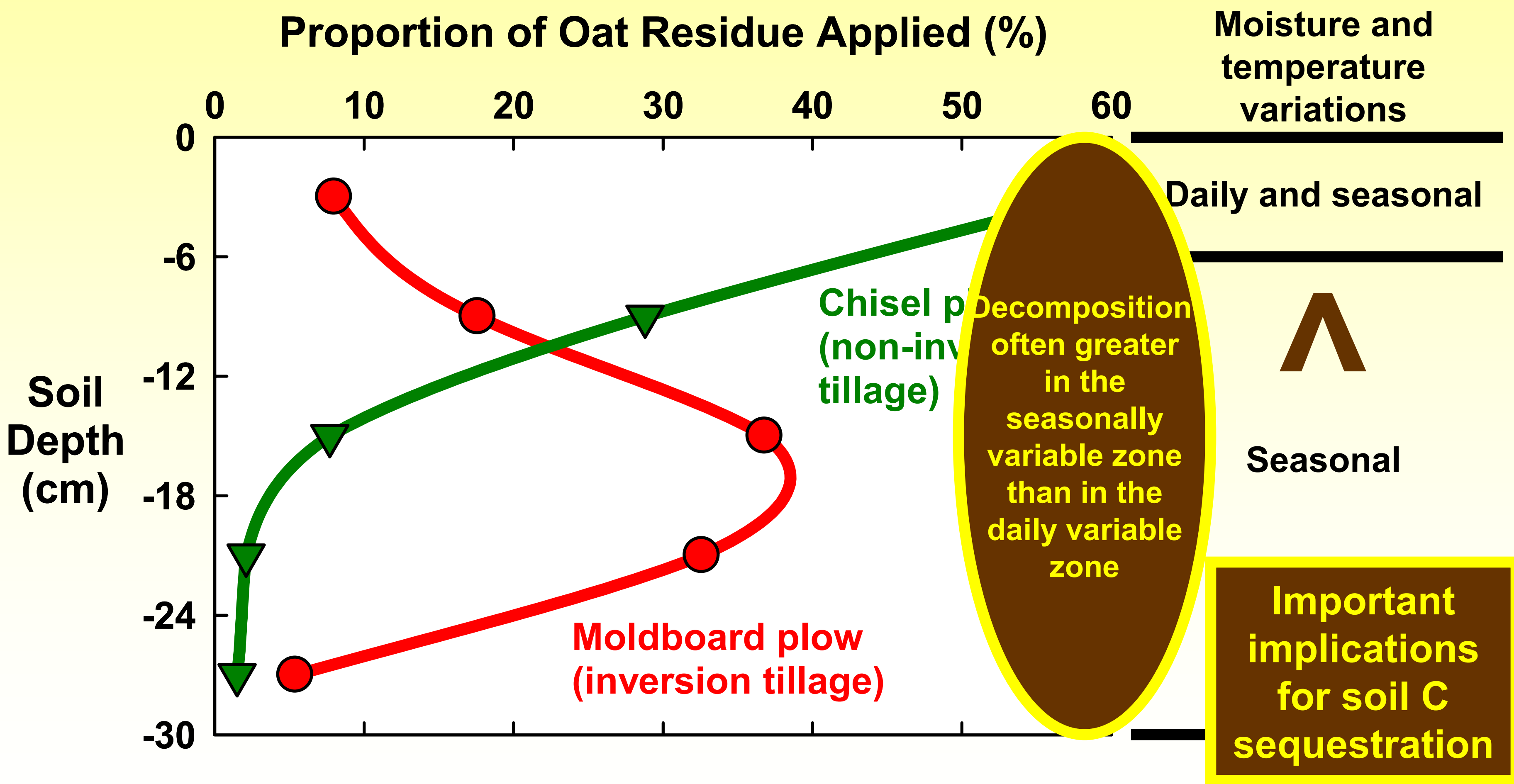
Conservation agriculture

Key components
- ✓ Minimal soil disturbance
- ✓ Continuous plant and/or residue cover
- ✓ Diversified crop rotations

To avoid soil organic matter loss from erosion and microbial decomposition

Soil Carbon Sequestration

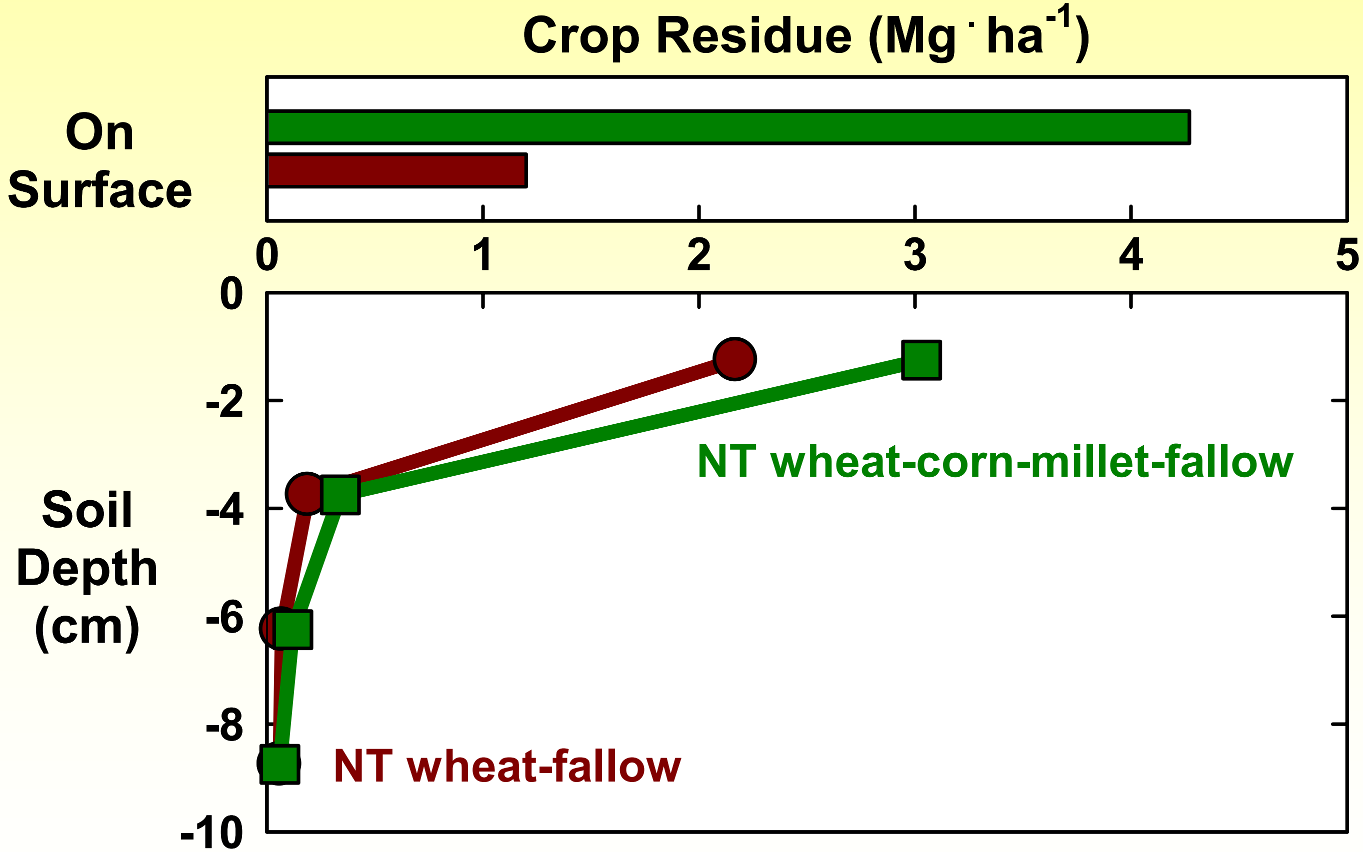
Crop residue distribution and the soil environment



Data from Allmaras et al. (1996) Soil Sci. Soc. Am. J. 60:1209-1216

Soil Carbon Sequestration

Cropping system inputs

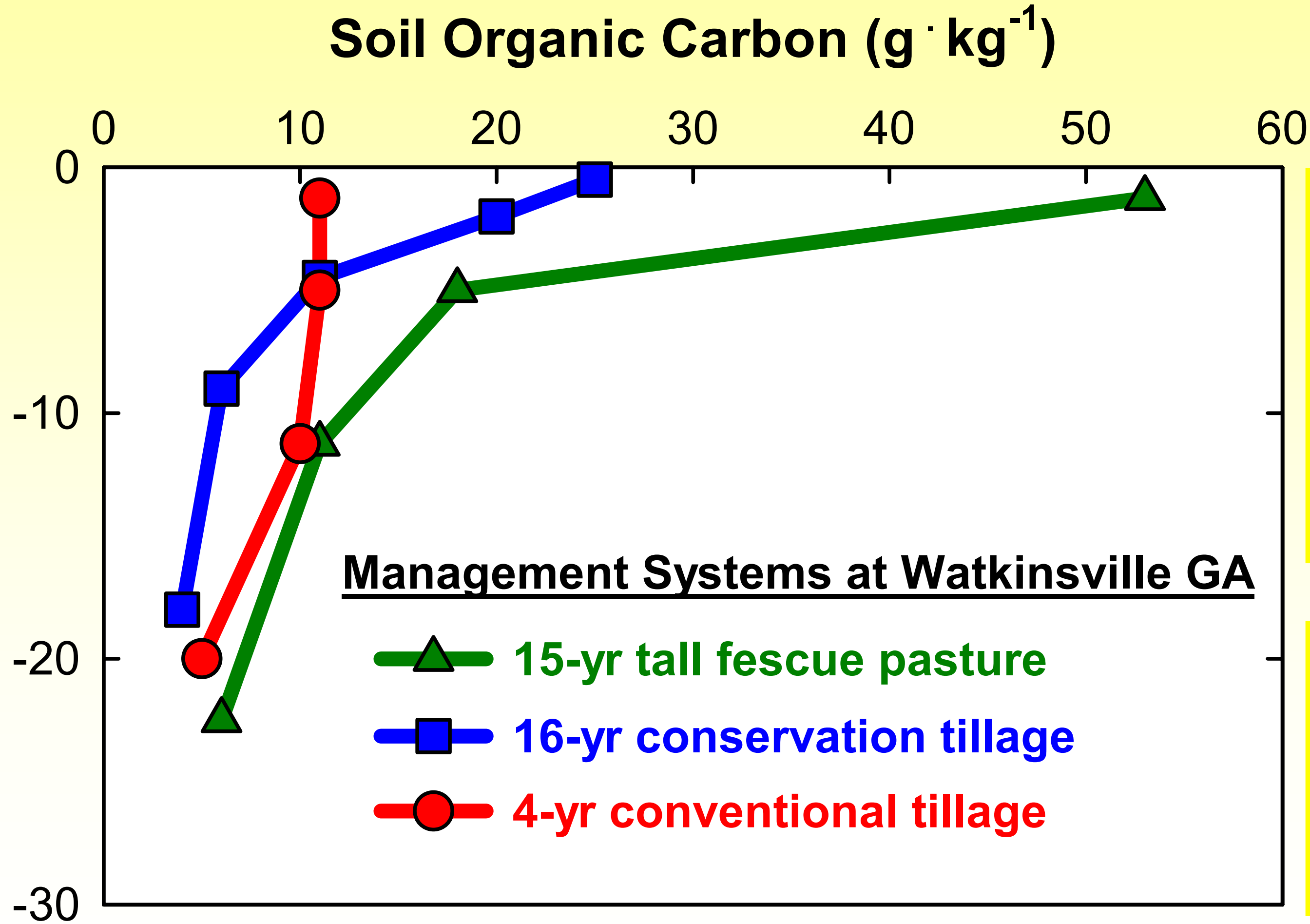


More intensive (productive) systems have greater potential for C input

Data from Ortega et al. (2002) Agron. J. 94:944-954

Soil Carbon Sequestration

Depth distribution of soil organic C (SOC)



Enormous benefit of conservation agricultural systems on SOC at the soil surface

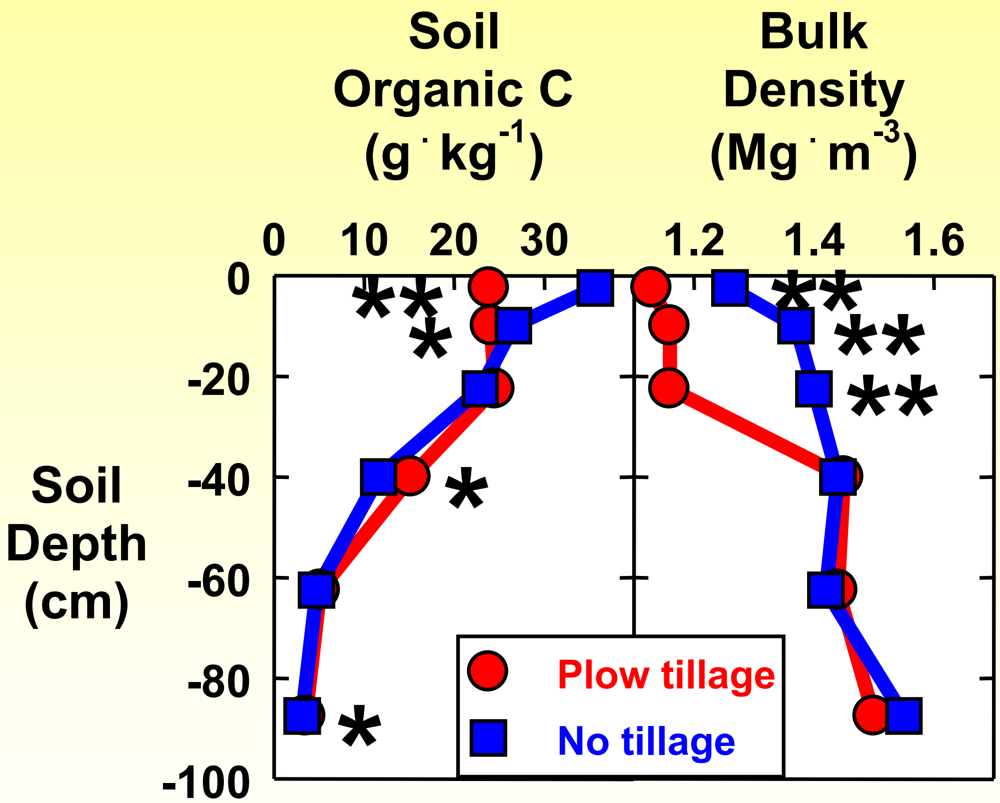
+

↑ surface SOC affects many other ecosystem processes

From Schnabel et al. (2001) Ch. 12, Pot. U.S. Grazing Lands Sequester C, Lewis Publ.

Soil Carbon Sequestration

Soil-profile distribution of soil organic C



Carbon Content (Mg · ha^{-1}) PT		NT	Cumulative Carbon Sequestration Rate (Mg/ha/yr)
13.6	<<	22.5	0.32
27.9	<<	36.4	0.62
42.8	<	48.2	0.81
43.9	>	33.3	0.44
18.2		16.7	0.38
12.8		12.2	0.36
Soil (0-30 cm) 84.1	<	107.0	
Soil (0-100 cm) 159.2	<	169.3	

Replicated experiment
Indiana – SiCL
Typic Haplaquoll
28-yr study
Corn and corn/soybean

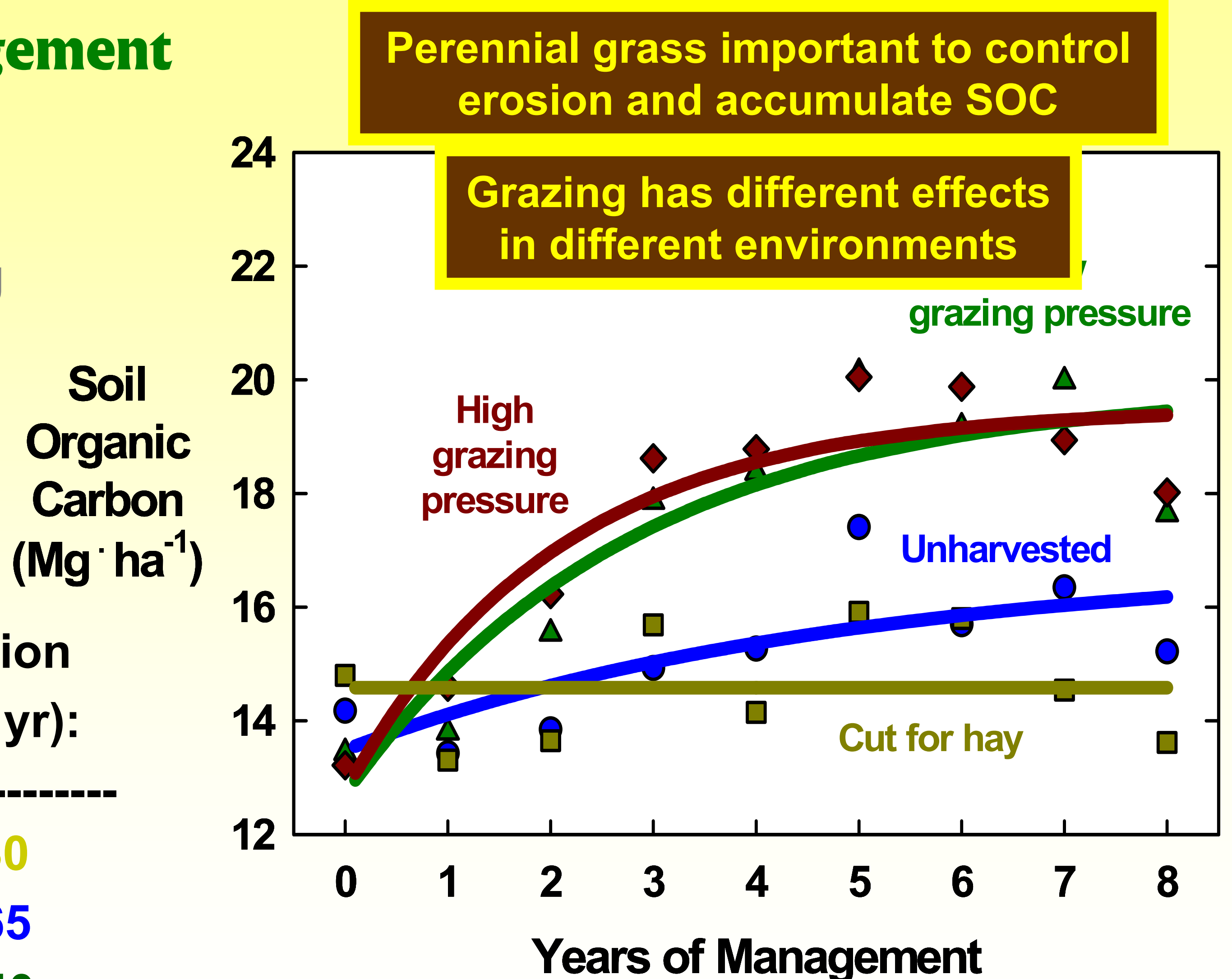
Depth of sampling can be very important

Data from Gál et al. (2007) Soil Till. Res. 96:42-51

Soil Carbon Sequestration

Pasture management

Establishment of bermudagrass pasture following long-term cropping in Georgia USA (16 °C, 1250 mm)



Soil C sequestration

($Mg\ ha^{-1}\ yr^{-1}$) (0-5 yr):

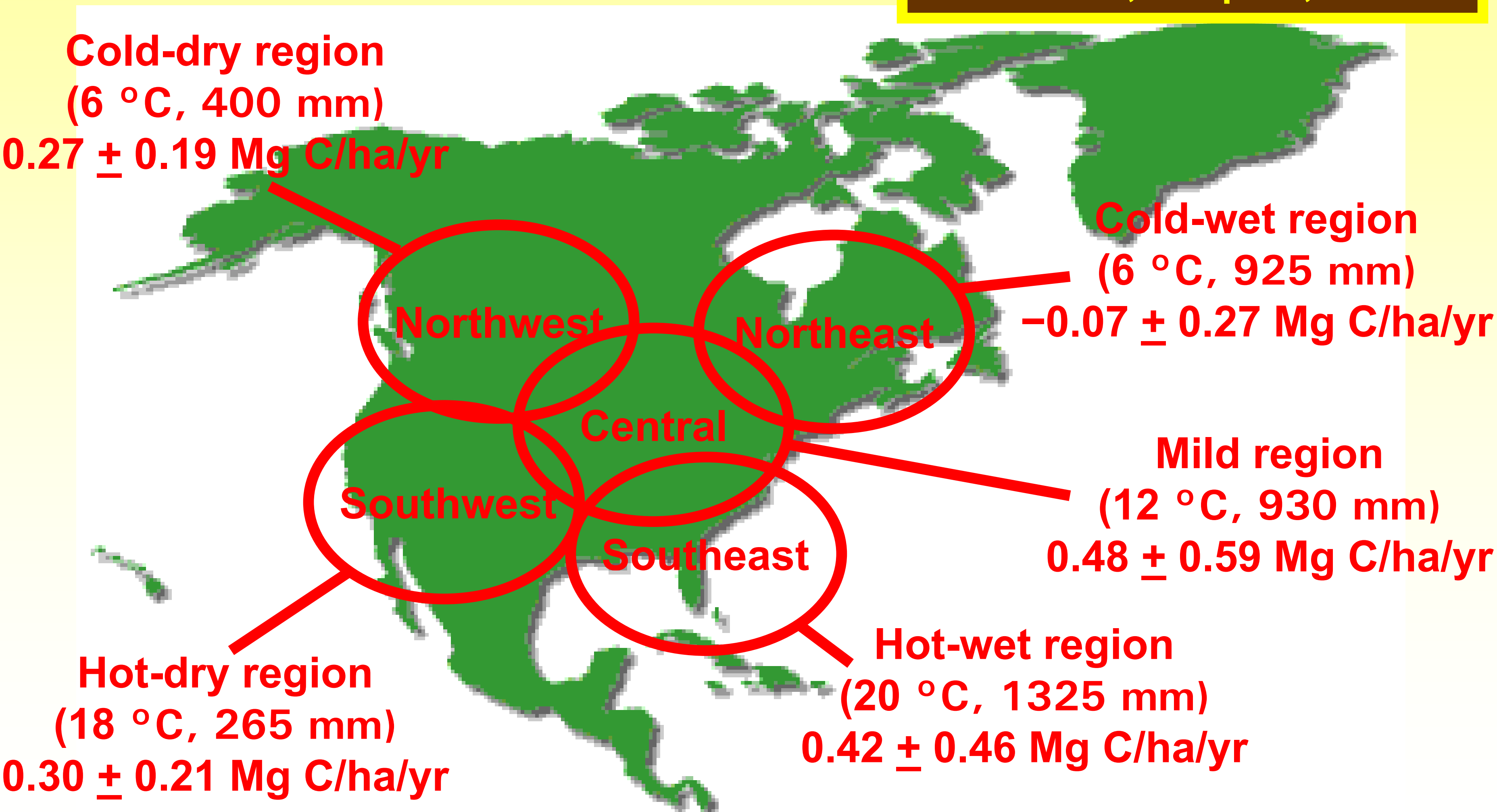
Hayed	0.30
Unharvested	0.65
Grazed	1.40

Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65:834-841 and unpublished data

Soil Carbon Sequestration

Conservation-tillage cropping

Regional differences due to climate, C inputs, etc.



Franzluebbers and Follett (2005) Soil Tillage Res. 83:1-8

Soil Carbon Sequestration

Cover cropping

Photos of 2 no-tillage systems in Virginia USA

Review of Soil Organic C Sequestration in the Southeastern USA

0.28 ± 0.44 Mg C/ha/yr (without cover cropping)

0.53 ± 0.45 Mg C/ha/yr (with cover cropping)

No-tillage cropping needs high-residue producing cropping systems (e.g. cover cropping) to be most effective

Franzluebbers (2005) Soil Tillage Res. 83:120-147.

Soil Carbon Sequestration

Crop residue harvest

At end of 7 years

Response 0-20-cm depth		Silage Crop Removal		
	Initially	0.5 yr^{-1}		1-2 yr^{-1}
Bulk density (Mg m^{-3})	1.43	1.37	ns	1.39
Macroaggregate stability (g g^{-1})	0.74	0.87	*	0.81
Soil organic C (mg g^{-1})	11.7	14.3	*	12.5
		↑ Low Intensity		↑ High Intensity

Crop residue harvest can have negative impacts on soil C and quality

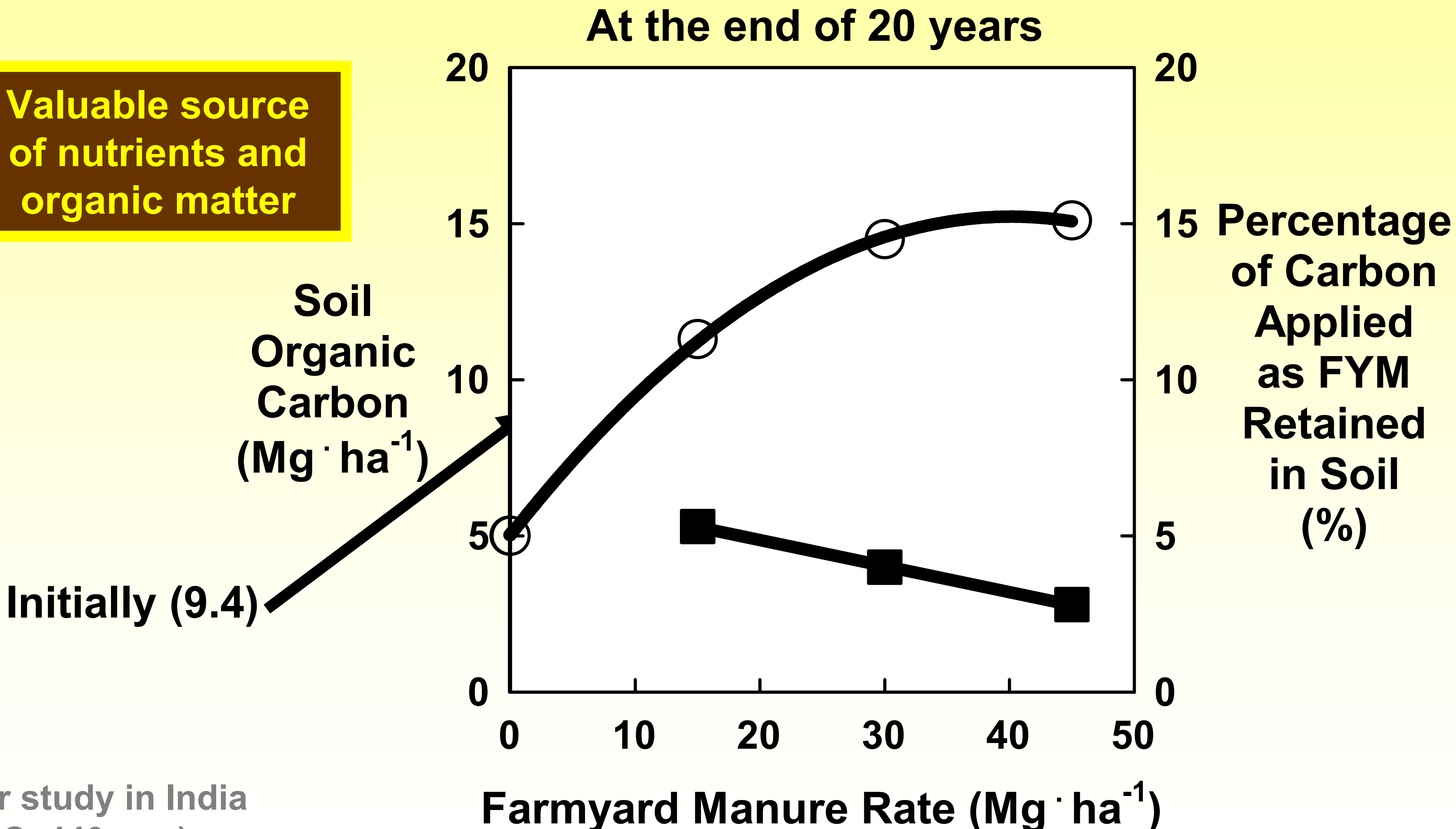
On-farm research
North Carolina Piedmont
Corn silage each year vs corn silage less often

Franzluebbers and Brock (2007)
Soil Till. Res. 93:126-137

Soil Carbon Sequestration

Animal manure application

Valuable source of nutrients and organic matter



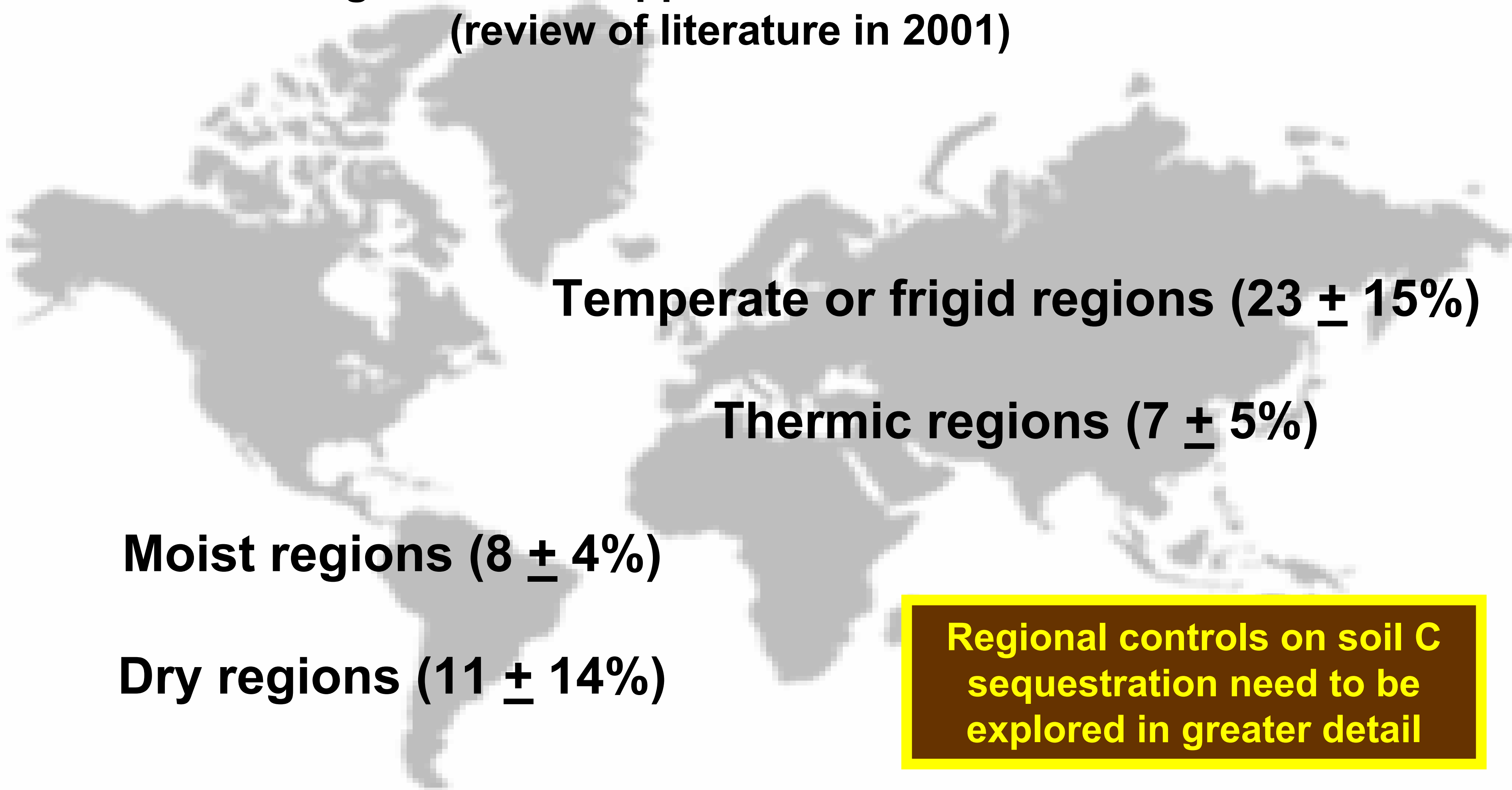
20-yr study in India
(26 °C, 440 mm)
Pearl millet–wheat

Data from Gupta et al. (1992) Arid Soil Res. Rehabil. 6:243-251

Soil Carbon Sequestration

Animal manure application

Percentage of carbon applied as manure retained in soil (review of literature in 2001)



Temperate or frigid regions (23 ± 15%)

Thermic regions (7 ± 5%)

Moist regions (8 ± 4%)

Dry regions (11 ± 14%)

Regional controls on soil C sequestration need to be explored in greater detail

Soil Carbon Sequestration

Green manuring

At the end of 12 years of Sesbania green manuring in India (24 °C, 715 mm) (Singh et al., 2007; Soil Tillage Res. 94:229-238),

Soil organic C sequestration was 0.09 ± 0.03 Mg C ha^{-1} yr^{-1}

At the end of 13 years of wheat/soybean–maize cropping with and without vetch as a green-manure cover crop in southern Brazil (21 °C, 1740 mm) (Sisti et al., 2004; Soil Tillage Res. 76:39-58):

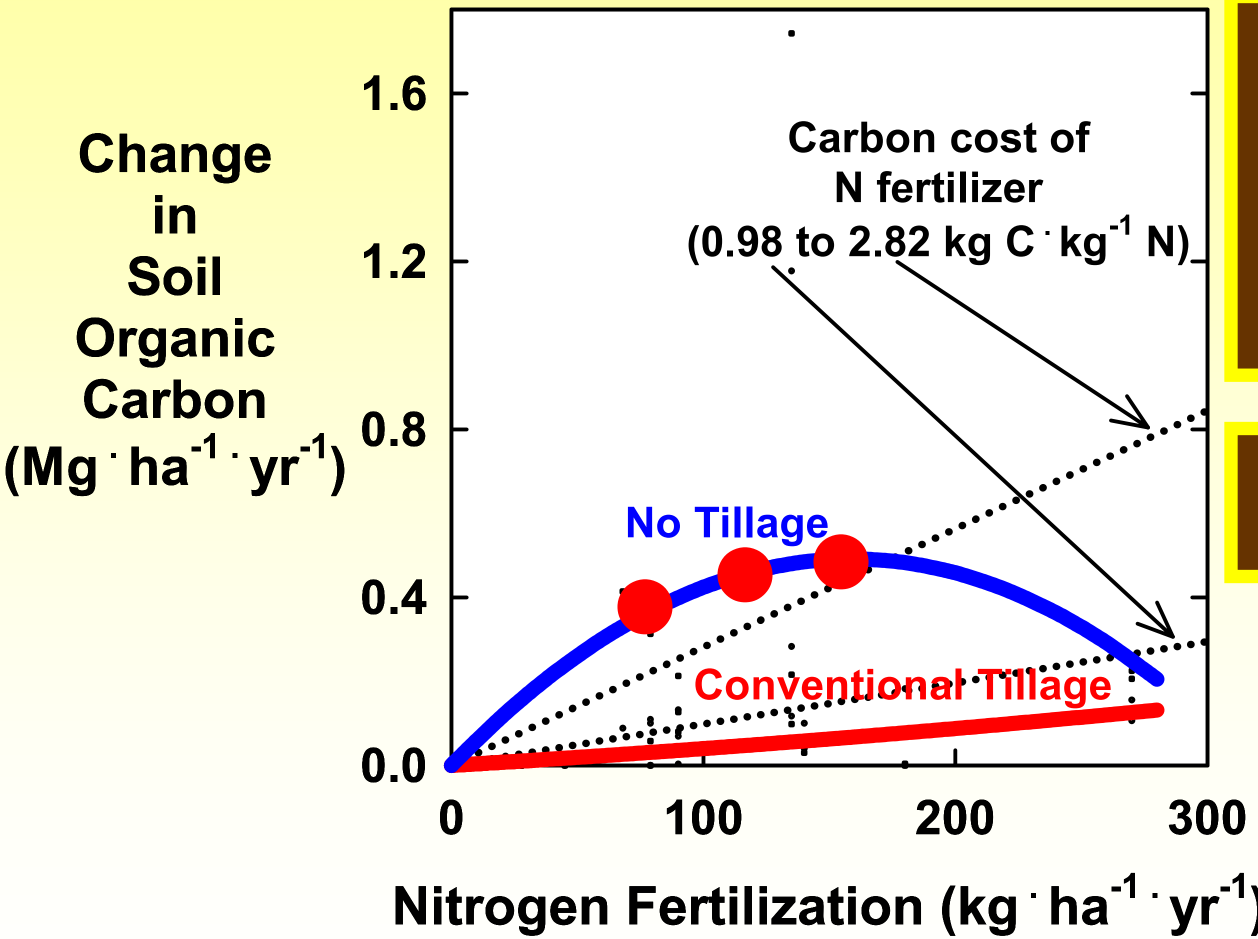
Tillage system	Soil organic C Change (Mg C ha^{-1} yr^{-1})
Conventional	−0.30 ± 0.15
Zero tillage	0.66 ± 0.26

Carbon input from biological N fixation and minimal disturbance best

Photo by Bob Bugg, www.ucdavis.edu

Soil Carbon Sequestration

Nitrogen fertilization



Therefore, soil carbon sequestration needs to be evaluated with a system-wide approach that includes all costs and benefits

System-wide accounting is a formidable challenge!

$1 \text{ kg } N_2O\text{-}N \text{ ha}^{-1} = 127 \text{ kg C ha}^{-1}$

Franzluebbers (2005) Soil Tillage Res. 83:120-147

Soil Carbon Sequestration

Crop type and sequence	Change in Soil Organic Carbon during 18 Years (Mg C ha^{-1} yr^{-1}) 0-7.5 cm depth	Change in Soil Organic Carbon during 18 Years (Mg C ha^{-1} yr^{-1}) 0-30 cm depth
Continuous corn (C) or sorghum (S)	-0.04	-0.23
Continuous soybean (SB)	-0.06	-0.30
2-yr rotation (C or S – SB)	-0.02	-0.17
4-yr rotation (O/Cl – C – SB – S)	0.05	-0.04

Importance of (1) type and (2) amount of C input from crop residues

Mead NE
Sharpsburg silty clay loam
Sampled in Years 0, 8, 14, 18

Data from Varvel (2006) Soil Sci. Soc. Am. J. 70:426-433

Nitrous Oxide Emission

Crop type and sequence

Emission (kg N_2O-N ha^{-1})

Crop rotation	Crop: Corn	Crop: Soybean	Crop: Wheat
Monoculture	2.62 ± 1.82	0.84 ± 0.52	0.51 ± 0.15
CO_2 equivalence (Mg C ha^{-1} yr^{-1})	0.33	0.11	0.06
Corn/soybean	1.34 ± 0.52	0.70 ± 0.43	–
	0.17	0.09	
Corn/soybean/wheat	1.64 ± 0.76	0.73 ± 0.24	0.72 ± 0.33
	0.21	0.09	0.09

Woodslee ON
Brookston clay loam
In Years 2, 3, and 4
Fertilizer – 170 kg N/ha corn,
83 kg N/ha wheat,
none for soybean

Importance of (1) N fertilizer rate, (2) type and amount of residue from previous crop, and (3) residual N

Data from Drury et al. (2008) Can. J. Soil Sci. 88:163-174

Nitrous Oxide Emission

Cropping, tillage, and fertilization

← All important

Emission (kg N_2O-N ha^{-1})

Condition	Annual crops / fall incorporation	Annual crops / not incorporated	Perennial crops / not incorporated
Winter/spring (n= 6-10)	2.41 ± 1.79	1.19 ± 0.79	0.29 ± 0.39
CO_2 equivalence (Mg C ha^{-1} yr^{-1})	0.31	0.15	0.04

Condition	Moldboard plow	No tillage
Tillage (n=15)	1.60 ± 3.16	1.96 ± 4.66
	0.20	0.25

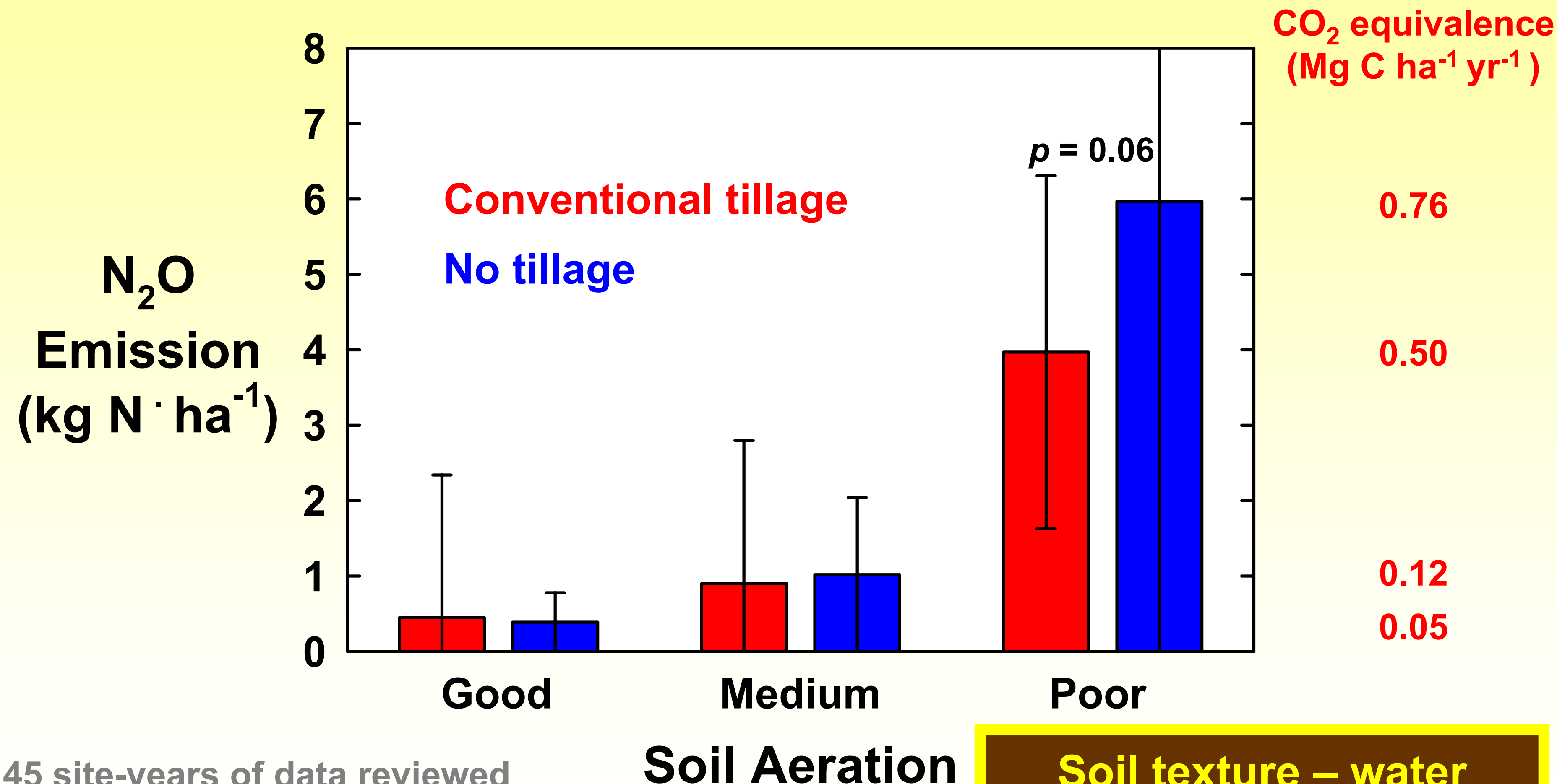
Condition	− N fertilizer	+ N fertilizer
Annual crops (n=14-57)	1.53 ± 1.00	2.82 ± 2.78
Perennial crops (n=6-9)	0.16 ± 0.21	0.62 ± 1.10
	0.19	0.36
	0.02	0.08

Review of eastern Canada studies

Data from Gregorich et al. (2005) Soil Till. Res. 83:53-72

Nitrous Oxide Emission

Interaction of tillage with soil type



45 site-years of data reviewed
Brazil, Canada, France, Japan, New Zealand, United Kingdom, USA

Soil texture – water management important

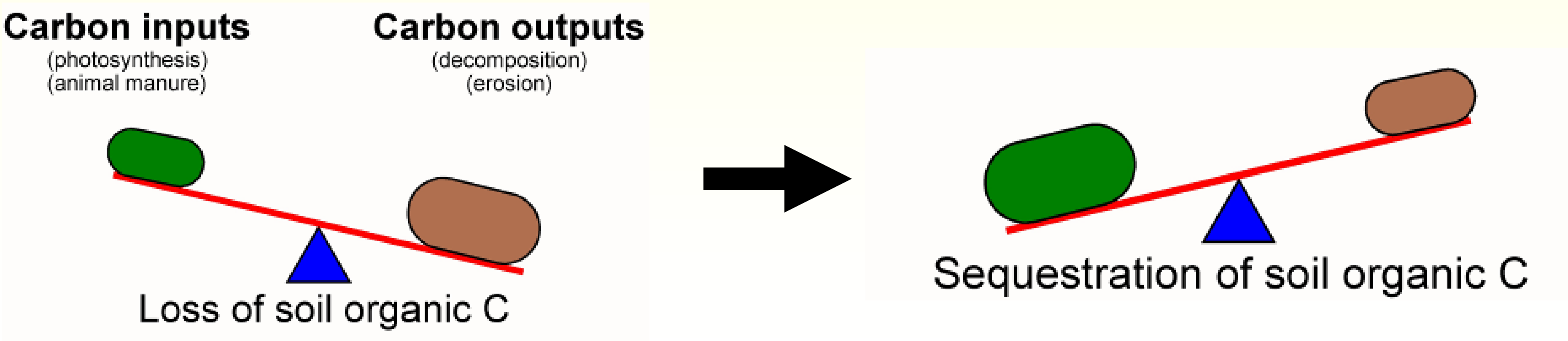
Data from Rochette (2008) Soil Till. Res. 101:97-100

Soil Carbon Sequestration

Summary

Soil organic carbon can be sequestered with adoption of conservation agricultural practices

- ✓ Enhanced soil fertility and soil quality
- ✓ Mitigation of greenhouse gas emissions
- ✓ Soil surface change is most notable
- ✓ Long-term changes are most scientifically defensible



Soil Carbon Sequestration

Acknowledgements

Funding

Agricultural Research Service (ARS)
US-Department of Energy
Madison County Cattleman's Association
USDA-National Research Initiative – Soil Processes
Cotton Incorporated
Georgia Commodity Commission for Corn
The Organic Center
ARS GRACEnet team

Contact:

Alan J. Franzluebbers
USDA – Agricultural Research Service
1420 Experiment Station Road
Watkinsville GA 30677 USA

Tel: 1-706-769-5631
Fax: 1-706-769-8962
Email:
alan.franzluebbers@ars.usda.gov

http://www.ars.usda.gov/main/site_main.htm?modecode=66-12-09-00